

1                   PCB WITH EMBEDDED OPTICAL FIBER

2

3

4                   Field of the Invention

5

6         This invention relates to high speed high data  
7   interconnect apparatus and methods.

8

9         More particularly, this invention relates to optical  
10   fibers embedded in printed circuit boards and coupled to  
11   interconnect [semiconductor chips or die] photonic  
12   components or die and semiconductor chips or die.

13

14

15                   Background of the Invention

16

17         In the electronic industry, there is a need for high  
18   speed optical interconnects to pass signals from  
19   semiconductor chip to semiconductor chip and board to board  
20   in order to fully utilize the emerging capabilities of  
21   microprocessors, digital signal processors, etc. A Pentium  
22   4<sup>TM</sup> microprocessor, for example, operates at 2.4 GHz but the  
23   data travels on a bus operating at only 400 MHz. The speed  
24   picks up again on an optical fiber telecommunication  
25   network. In accordance with to Moore's Law, single chip

1 microprocessors can eventually achieve speeds of tens of  
2 teraflops. However, the speed limitation of current copper  
3 bus structures is limited at best to 10 GHz. High speed  
4 optical interconnect applications are primarily in computers  
5 (commercial and military), telecommunications switches, etc.

6

7 A number of problems need to be overcome to produce  
8 high performance manufacturable optical interconnects that  
9 can utilize the existing surface mount manufacturing  
10 infrastructure. In any product using optical interconnects  
11 there will be a large number of Silicon die. The reason for  
12 this is, at the present time, there is only one way to bring  
13 software into a system and that is with Silicon. Thus, in  
14 the present technology, economics require that any board  
15 with optical interconnects be surface mount compatible.

16

17 For distances of up to 500 meters, 850 nm emitters and  
18 detectors are currently the emitters and detectors of  
19 choice. For these distances, data rates far in excess of 1  
20 GHz are readily achievable using glass optical multimode  
21 fiber. Optical glass fiber is preferred over organic  
22 optical fibers both from an optical power loss and  
23 achievable data rate.

24

1        It would be highly advantageous, therefore, to remedy  
2 the foregoing and other deficiencies inherent in the prior  
3 art.

4        It is an object of the present invention to provide a  
5 new and improved printed circuit board with embedded optical  
6 fiber for use as a high speed, high data rate interconnect.

7

8        It is another object of the present invention to  
9 provide a new and improved printed circuit board with  
10 embedded optical fiber that is highly manufacturable.

11

12       It is another object of the present invention to  
13 provide a new and improved printed circuit board with  
14 embedded optical fiber that is compatible with surface  
15 mounting techniques.

16

17       It is another object of the present invention to  
18 provide a new and improved printed circuit board with  
19 embedded optical fiber that is highly manufacturable.

### Summary of the Invention

The above problems and others are at least partially solved and the above objects and others realized in new and improved high speed data interconnect apparatus, and method of fabrication, including a stiffening plate with optical fiber mounting groove defined on a surface thereof and a length of optical fiber mounted in the groove. The optical fiber includes opposed ends and defines an optical path between the opposed ends. The optical fiber is mounted in the groove on the surface of the stiffening plate in a longitudinally extending direction generally parallel to the surface of the stiffening plate. A reflecting surface is positioned adjacent one of the opposed ends of the optical fiber to direct light at an angle of approximately ninety degrees to the optical path. A printed circuit board laminate encases the stiffening plate and optical fiber and includes a light via for the passage of light reflected by the reflecting surface. Bond pads are formed on a surface of the printed circuit board laminate adjacent the light via for the electrical connection of a light element, such as a vertical cavity surface emitting laser or a photo diode.

23  
24 The invention also proposes new and improved high speed  
25 data interconnect apparatus, and method of fabrication,

1 including a stiffening plate with an elongated optical fiber  
2 mounting groove defined on a surface thereof and a length of  
3 optical fiber mounted in the groove. The optical fiber  
4 includes first and second opposed ends and defines an  
5 optical path between the opposed ends. The optical fiber is  
6 mounted in the groove on the surface of the stiffening plate  
7 in a longitudinally extending direction generally parallel  
8 to the surface of the stiffening plate. A first reflecting  
9 surface is positioned adjacent the first opposed end of the  
10 optical fiber, the first reflecting surface being positioned  
11 to direct light at an angle of approximately ninety degrees  
12 to the optical path. A second reflecting surface is  
13 positioned adjacent the second opposed end of the optical  
14 fiber, the second reflecting surface being positioned to  
15 direct light at an angle of approximately ninety degrees to  
16 the optical path. A printed circuit board laminate encases  
17 the stiffening plate and the optical fiber and includes a  
18 first light via for the passage of light reflected by the  
19 first reflecting surface and a second light via for the  
20 passage of light reflected by the second reflecting surface.  
21 First bond pads are formed on a surface of the printed  
22 circuit board laminate adjacent the first light via and  
23 second bond pads are formed on the surface of the printed  
24 circuit board laminate adjacent the second light via. A  
25 vertical cavity surface emitting laser is mounted on the

1 surface of the printed circuit board laminate in light  
2 communication with the first light via, using the first bond  
3 pads. A photo detector is mounted on the surface of the  
4 printed circuit board laminate in light communication with  
5 the second light via, using the second bond pads.

1                   Brief Description of the Drawings

2

3         The foregoing and further and more specific objects and  
4         advantages of the invention will become readily apparent to  
5         those skilled in the art from the following detailed  
6         description taken in conjunction with the drawings in which:

7

8         FIG. 1 illustrates an embodiment of a printed circuit  
9         board with embedded optical fiber in accordance with the  
10        present invention;

11

12        FIGS. 2 and 3 illustrate end and side views,  
13        respectively, of the optical fiber used in the printed  
14        circuit board of FIG. 1;

15

16        FIG. 4 is an end view of the printed circuit board of  
17        FIG. 1, illustrating the position of the embedded optical  
18        fiber;

19

20        FIG. 5 is an end view illustrating another method of  
21        mounting an optical fiber in a printed circuit board;

22

23        FIG. 6 is an end view illustrating another method of  
24        mounting an optical fiber in a printed circuit board;

1       FIG. 7 illustrates an embodiment of a printed circuit  
2 board with optical fiber embedded in using one of the  
3 methods illustrated in FIGS. 5 or 6 in accordance with the  
4 present invention;

5

6       FIG. 8 illustrates another embodiment of a printed  
7 circuit board with embedded optical fiber in accordance with  
8 the present invention;

9

10      FIG. 9 is a view in [top plan] cross-section  
11 illustrating an embodiment of [a] multiple stiffening plates  
12 used in the printed circuit board, in accordance with the  
13 present invention;

14

15      FIG. 10 illustrates another embodiment of a printed  
16 circuit board with embedded optical fiber in accordance with  
17 the present invention;

18

19      FIG. 11 illustrates another embodiment of a printed  
20 circuit board with embedded optical fiber in accordance with  
21 the present invention;

22

23      FIG. 12 illustrates another embodiment of a printed  
24 circuit board with embedded optical fiber in accordance with  
25 the present invention;

1           FIG. 13 illustrates another embodiment of a printed  
2 circuit board with embedded optical fiber in accordance with  
3 the present invention; and

4

5           FIG. 14 illustrates a combination of printed circuit  
6 boards formed in accordance with the embodiment illustrated  
7 in FIG. 13.

1                   Detailed description of the Drawings

2

3         Turning to the drawings, attention is first directed to  
4 Fig. 1, which illustrates an embodiment of high speed data  
5 interconnect apparatus 10 including a printed circuit board  
6 12 with embedded optical fiber 14 in accordance with the  
7 present invention. Here it will be understood that the term  
8 "printed circuit board" is interchangeable, in this  
9 disclosure, with the term "printed wiring board" and either  
10 are represented herein by the acronym PCB. Printed circuit  
11 board 12 includes a stiffening plate 16 formed of material  
12 having a coefficient of thermal expansion approximately  
13 matching the coefficient of thermal expansion of optical  
14 fiber 14. Matching the coefficients eliminates or greatly  
15 reduces any relative movement between stiffening plate 16  
16 and optical fiber 14, thereby substantially eliminating  
17 stress in optical fiber 14. In a preferred embodiment,  
18 stiffening plate 16 is formed of a nickel iron alloy, the  
19 coefficient of thermal expansion of which can be precisely  
20 matched (by adjusting the composition of the alloy) to the  
21 coefficient of thermal expansion of optical fiber 14.

22

23         An elongated optical fiber mounting groove 20, one  
24 embodiment of which is illustrated in FIG. 4, is formed in  
25 the surface of stiffening plate 16. Groove 20 has a

1 generally rectangular shaped cross-section with a depth and  
2 width approximately equal to a diameter of the length of  
3 optical fiber 14. Groove 20 is fabricated with a width and  
4 depth slightly greater than (approximately equal to) the  
5 outside diameter of optical fiber 14. Groove 20 can be  
6 fabricated by any of the well known semiconductor  
7 fabrication processes, such as sawing (in a manner similar  
8 to wafer sawing), chemical etching, laser machining, or by  
9 electron beam machining. As will be understood, groove 20  
10 need not be a straight line. Further, while a single groove  
11 20 is illustrated herein for purposes of explanation, it  
12 will be understood that multiple grooves can be fabricated  
13 as required by specific applications. For best results, the  
14 width of groove 20 should not exceed the outside diameter of  
15 optical fiber 14 (assuming a multi mode fiber with an  
16 outside diameter of approximately 125 microns and a core  
17 diameter in a range of 50 to 62.5 microns) by more than 10  
18 microns.

19

20       Another potential embodiment of an elongated optical  
21 fiber mounting groove, designated 21, is illustrated in FIG.  
22 5. In this embodiment groove 21 has a shallow rectangular  
23 shaped cross-section with a depth and width smaller than the  
24 diameter of optical fiber 14. Groove 21 can be conveniently  
25 fabricated by the process of metal skiving. This process

1 produces a shallow rectangular groove with precise width and  
2 depth. It will of course be understood that other processes  
3 can be utilized to fabricate groove 21, such as any of the  
4 processes mentioned above. Groove 21 has the advantage of  
5 requiring the removal of less material from stiffening plate  
6 16 and generally a simpler fabrication process but provides  
7 less support for optical fiber 14.

8

9 Another potential embodiment of an elongated optical  
10 fiber mounting groove, designated 22, is illustrated in FIG.  
11 6. In this embodiment groove 22 has a generally V-shaped  
12 cross-section fabricated by a process of metal scribing.  
13 The metal scribing process produces a shallow V-shaped  
14 groove with precise depth and sidewall angle. Groove 22 has  
15 the advantage of requiring the removal of less material from  
16 stiffening plate 16 and generally a simpler fabrication  
17 process but provides less support for optical fiber 14.

18

19 Optical fiber 14 is positioned in groove 20, for  
20 purposes of explanation, in a longitudinally extending  
21 direction generally parallel to the surface of stiffening  
22 plate 16. Although multimode optical fiber is used for  
23 purposes of this explanation, nothing in the invention  
24 precludes applying the technology to the use of single mode  
25 optical fiber applications (i.e. 1300 nm and 1500 nm).

1 Optical fiber 14 can be locked in place by an adhesive  
2 dispensed into groove 20 prior to insertion of optical fiber  
3 14. Optical fiber 14 has opposed ends 24 and 26 with  
4 reflecting surfaces 25 and 27 positioned adjacent thereto,  
5 respectively. Reflecting surfaces 25 and 27 are positioned  
6 to direct light at an angle of approximately ninety degrees  
7 to an optical path 32 between opposed ends 24 and 26 of  
8 optical fiber 14, i.e. the longitudinal axis of optical  
9 fiber 14. Several different embodiments of reflecting  
10 surfaces 25 and 27 can be devised, some examples of which  
11 are explained below. Here it will be understood that while  
12 both ends 24 and 26 of optical fiber 14 have an associated  
13 reflecting surface in the embodiment of high speed data  
14 interconnect apparatus 10 illustrated in FIG. 1, other  
15 embodiments are contemplated, some of which are explained  
16 below, in which only one end has an associated reflecting  
17 surface.

18

19 In a first embodiment, illustrated in detail in FIGS. 2  
20 and 3, the reflecting surface 25 associated with end 24 is  
21 illustrated for purposes of this explanation. Reflecting  
22 surface 25 includes an angular cut in optical fiber 14  
23 adjacent opposed end 24 to define a cut surface 30  
24 positioned at an angle of approximately 45 degrees to the  
25 optical path 32. To enhance reflection, cut surface 30 is

1 mirrored or otherwise coated with a reflecting material. It  
2 will be understood that mirroring or coating is optional and  
3 sufficient coating may be provided by the adhesive material  
4 in groove 20 to provide the desired reflecting  
5 characteristics. [ I assume the prior sentence broadens the  
6 patent although the reflecting surface most likely will be  
7 mirrored.] Optical fiber 14, consisting of core 34 and  
8 cladding 35, has a portion 36 (see FIG. 3) of cladding 35  
9 removed in a small section opposite cut surface 30 to allow  
10 light to enter or exit optical fiber 14.

11

12 In another embodiment, illustrated in detail in FIG. 7,  
13 the reflecting surfaces include micro mirrors 40 and 42  
14 mounted in groove 20 on the surface of stiffening plate 16  
15 in optical alignment with optical path 32 and a light via,  
16 to be explained presently. In this embodiment, components  
17 of high speed data interconnect apparatus 10 similar to  
18 components in the embodiment of FIG. 1 are designated with  
19 similar numbers to indicate the interchangeability of the  
20 various components. In this embodiment optical fiber 14 has  
21 simply cleaved and polished ends so that no rotational  
22 alignment is needed. Small 45 degree micro mirrors 40 and  
23 42 are inserted and bonded into groove 20, which is extended  
24 slightly in length to accommodate the mirrors. In a  
25 slightly different embodiment, a 45 degree chamfer is cut

1 into one or both ends of groove 20 and plated with a non  
2 tarnishing reflecting plating (such as nickel/gold, etc.) to  
3 form reflecting surfaces or mirrors.

4

5         Turning now to FIG. 8, another embodiment of reflecting  
6 surfaces in association with the ends of optical fiber 14 is  
7 illustrated. In this embodiment the ends 24 and 26 are  
8 simply cleaved and polished so that no rotational alignment  
9 is needed. Optical fiber portions 44 and 46, each with an  
10 approximately 45 degree mirrored end, are mounted in groove  
11 20 in optical alignment with optical path 32 and a light via  
12 in association with ends 24 and 26, respectively, of optical  
13 fiber 14. Generally, optical fiber portions 44 and 46 will  
14 be formed from an optical fiber similar to optical fiber 14  
15 (in this embodiment a multi mode optical fiber) so as to  
16 match diameters. Preferably, the ends of optical fiber  
17 portions 44 and 46 are chamfered at 45 degrees and mirrored  
18 for optimum reflecting characteristics. In addition to or  
19 in lieu of beveled mirrored optical fiber portions,  
20 reflecting surfaces can be made from wire or other structure  
21 with a circular, square, rectangular, or other cross-  
22 section, which is beveled and metalized or otherwise  
23 mirrored.

24

1 Referring again to FIG. 1, a printed circuit board  
2 laminate 50 is applied to stiffening plate 16, both upper  
3 and lower surfaces, to encase 'stiffening plate 16 and  
4 optical fiber 14. In the preferred embodiment, Teflon is  
5 included as the laminate because of its bonding and thermal  
6 characteristics but any other known material for fabricating  
7 printed circuit boards can be used. Alignment marks are  
8 provided on stiffening plate 16 for use in guiding the  
9 positioning of a laminate conductor pattern with bond pads  
10 52 to allow the affixing of solder bumped photonic or  
11 semiconductor die and the like directly to the printed  
12 circuit board produced by the laminate process. After  
13 lamination and conductor patterning of the layer or layers  
14 of laminate 50 one or more vias, e.g. vias 54 and 56, can be  
15 opened through laminate 50 in alignment with reflecting  
16 surfaces 25 and 27, respectively. Vias 54 and 56 can be  
17 opened, for example by laser ablation, or they can be pre-  
18 punched prior to lamination. For example, a CO<sub>2</sub>, YAG, or  
19 Eximer laser can be used to ablate vias. Laminate 50 can  
20 have vias 54 and 56 pre-punched and by precisely aligning  
21 laminate 50 with stiffening plate 16 and bonding the two  
22 together, no ablation of vias is required. This printed  
23 circuit board concept allows other supporting semiconductor  
24 dies to be mounted and interconnected so that data generated

1 can be converted from electrical to optical or optical to  
2 electric as will become apparent presently.

1       To maintain the positional accuracy of light elements  
2 mounted above vias 54 and 56 to reflecting surfaces 25 and  
3 27, laminate 50 on which they are mounted is preferably not  
4 too thick so that stiffening plate 16 constrains the  
5 movement of the top surface of laminate 50. The nickel iron  
6 of stiffening plate 16 has a much higher Modulus of  
7 Elasticity than the Teflon of laminate 50. Generally, a  
8 thickness of Teflon laminate 50 up to two times the  
9 thickness of nickel iron stiffening plate 16 is preferred.  
10 If vias are included that go through stiffening plate 16,  
11 holes can be provided and plugged with Teflon, as  
12 illustrated in FIG. 9, prior to lamination to allow a  
13 continuous thickness of the Teflon. Generally, soft  
14 laminating material, such as Teflon, can be laminated  
15 directly over optical fiber 14 without causing damage to  
16 optical fiber 14. Stiffer laminates usually need to be  
17 recessed so as not to impose an unduly large stress on  
18 optical fiber 14. Such a recess can contain a soft bonding  
19 medium or encapsulant to fully enclose and protect optical  
20 fiber 14.

21  
22       Laminate 50 and bond pads 52 allow affixing light  
23 elements, such as vertical cavity surface emitting laser  
24 (VCSEL) 60 and photo detector 62, directly over vias 54 and  
25 56 leading to reflecting surfaces 25 and 27 associated with

1 opposed ends 24 and 26 of optical fiber 14. The light  
2 elements can either self-align using eutectic solder bumps  
3 64 or for non eutectic solder bumps be machine aligned and  
4 positioned precisely over reflecting surfaces 25 and 27. In  
5 this embodiment a VCSEL 60 is positioned, electrically  
6 connected, and physically held over via 54 using eutectic  
7 solder balls 64. Also, a photo detector 62 is positioned,  
8 electrically connected, and physically held over via 54  
9 using eutectic solder balls 64. [ Do we need a sentence  
10 here stating that it is recognized that solders other than  
11 eutectic can also be used?] Other supporting semiconductor  
12 die (not shown) are clustered around VCSEL 60 and photo  
13 detector 62 and electrically connected to each other and to  
14 VCSEL 60 and photo detector 62 by conductive traces in  
15 laminate 50. Thus, electrical signals at one location are  
16 converted to optical signals (light pulses) by VCSEL 60 and  
17 directed into optical fiber 14 by reflecting surface 25.  
18 The light pulses are directed onto photo detector 62 at a  
19 remote location by reflecting surface 27 and converted back  
20 to electrical signals, which are then coupled to a cluster  
21 of semiconductor die (not shown) adjacent photo detector 62.  
22 It will be understood that multiple numbers of optical  
23 interconnects can be incorporated on the same printed  
24 circuit board. In general, both VCSEL 60 and photo detector  
25 62 are encapsulated, after assembly, using a suitable

1   optical   under   encapsulant   to   provide   environmental  
2   protection.

1        Usually, VCSELs are fabricated in a package that  
2 includes a lens (see for example VCSEL 60 and lens 65 in  
3 FIG. 10) to focus substantially all of the optical energy  
4 onto the reflecting surface in the via aligned with the  
5 VCSEL. However, in the event that the VCSEL does not  
6 include a lens or to provide additional focusing, a lens 67  
7 (see FIG. 11) can be embedded in the associated via (e.g.  
8 via 54). Also, while focusing at the photo detector is  
9 generally not required, a lens or lenses can be included  
10 with the photo detector or in the associated via (e.g. photo  
11 detector 62 and via 56) if desired.

12

13        Turning now to FIG. 12, another embodiment is  
14 illustrated of high speed data interconnect apparatus,  
15 designated 100, including a printed circuit board 112 with  
16 embedded optical fiber 114 in accordance with the present  
17 invention. Components similar to components in FIG. 1 are  
18 designated with similar numbers, having a "1" added to  
19 indicate a different embodiment. In this embodiment a  
20 cavity 154 (similar to via 54 in FIG. 1) is formed in  
21 laminate 150 prior to bonding to stiffening plate 116 or  
22 could be laser machined in after bonding. An edge emitting  
23 laser 160 is positioned in cavity 154 in optical alignment  
24 with optical fiber 114 and die bonded to a suitably prepared  
25 surface on stiffening plate 116. Edge emitting laser 160 is

1 then wire bonded with wires 164 to bond pads 152 on laminate  
2 150. A suitable optical encapsulant is used to provided  
3 environmental protection to edge emitting laser 160. Also,  
4 a cover (not shown) is bonded over cavity 154 for finger  
5 protection and a suitable optical under encapsulant is used  
6 to provide environmental protection to surface mounted photo  
7 detector 162. It will be understood that an edge detector  
8 and VCSEL could be substituted for photo detector 162 and  
9 edged emitting laser 160, respectively, if desired. Also,  
10 an edge detector could be mounted in a cavity, similar to  
11 that shown for edge emitting laser 160, in place of surface  
12 mounted photo detector 162.

13

14 Turning now to FIG. 13, another embodiment is  
15 illustrated of high speed data interconnect apparatus,  
16 designated 200, including a printed circuit board 212 with  
17 embedded optical fiber 214 in accordance with the present  
18 invention. Components similar to components in FIG. 1 are  
19 designated with similar numbers, having a "2" added to  
20 indicate a different embodiment. In this embodiment, the  
21 optical interconnect is terminated in a printed circuit  
22 board optical edge connector 270. Here VCSEL 260 introduces  
23 optical signals (light pulses) into end 224 of optical fiber  
24 214 as described in conjunction with FIG. 1. However, the  
25 opposed end, end 226, has no reflecting surface associated

1 with it but terminates in a via 272 in optical edge  
2 connector 270. It will be understood that while VCSEL 260  
3 is illustrated for convenience, a photo detector, edge  
4 emitting laser or edge illuminated detector could be used as  
5 a light element in apparatus 200. Any of these components  
6 would be mounted and connected as these components are  
7 described above. As illustrated in FIG. 14, apparatus 200  
8 can then be coupled to an electro optical back plane 275 or  
9 the like through optical connectors 276.

10

11 Thus, a new and improved printed circuit board with  
12 embedded optical fiber has been described for use as a high  
13 speed, high data rate interconnect. The new and improved  
14 printed circuit board with embedded optical fiber is highly  
15 manufacturable and is compatible with surface mounting  
16 techniques presently used in the semiconductor industry.  
17 Also, a variety of optical elements, including VCSELs, photo  
18 detectors, edge emitting lasers, and edge illuminated  
19 detectors, can be easily incorporated with few changes to  
20 the basic structure.

21

22 Various changes and modifications to one or more of the  
23 embodiments herein chosen for purposes of illustration will  
24 readily occur to those skilled in the art. To the extent  
25 that such modifications and variations do not depart from

1 the spirit of the invention, they are intended to be  
2 included within the scope thereof, which is assessed only by  
3 a fair interpretation of the following claims.

4

5 Having fully described the invention in such clear and  
6 concise terms as to enable those skilled in the art to  
7 understand and practice the same, the invention claimed is: